TEMPERATURE MAPS OF CLUSTERS OF GALAXIES

GRANT
TR/IN/89
2001 /92 247

NASA Grant NAG5-6749

Annual Report

For the Period 1 January 2001 through 31 December 2001

Principal Investigator
Dr. William R. Forman

October 2001

Prepared for:

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

1 Annual Report for "Temperature Maps of Clusters of Galaxies" – NAG5-6749

We have progressed on our analysis of the temperature structure of clusters of galaxies. The next to last paper to be supported by this project has been submitted and accepted for publication in the ApJ (see Donnelly et al. astro-ph/0106482; and details below). The second paper, a survey, is nearing completion.

2 Merging Clusters

We have completed the paper "Merging Binary Clusters" by Donnelly, Forman, Jones, Quintana, Ramirez, Churazov, Gilfanov. We studied three prominent bimodal X-ray clusters: A3528, A1750 and A3395. Using observations taken with ROSAT and ASCA, we analyzed the temperature and surface brightness distributions. We also analyzed the velocity distributions of the three clusters using new measurements supplemented with previously published data. We examined both the overall cluster properties, as well as the two sub-cluster components within each cluster. These results were then applied to the determination of the overall cluster masses, and demonstrated excellent consistency between the various methods. While the characteristic parameters of the sub-clusters were typical of isolated objects, our temperature results for the regions between the two sub-clusters clearly confirmed the presence of merger activity. These three clusters represent a progression of equal-sized sub-cluster mergers, starting from initial contact to immediately before first core passage.
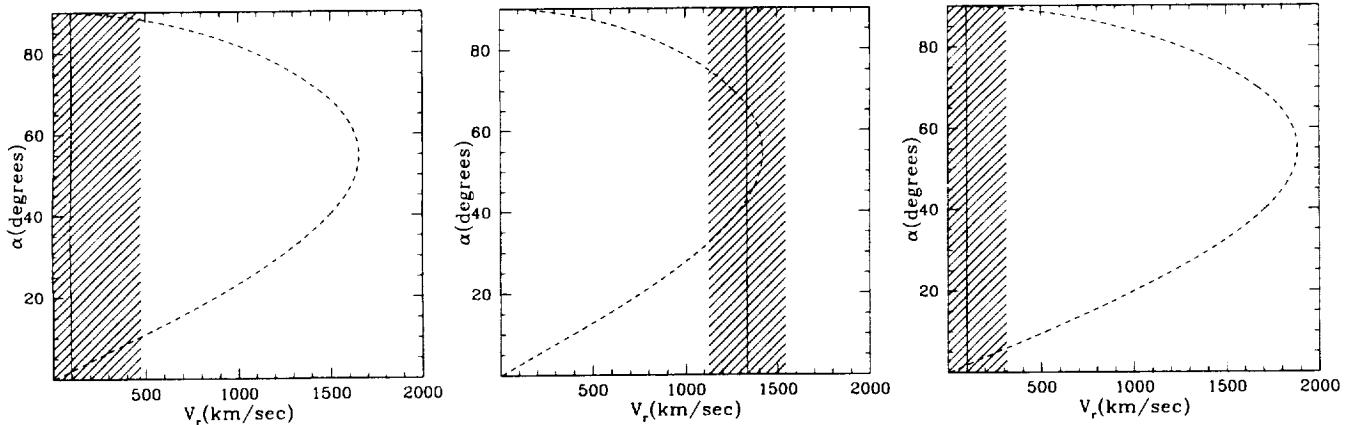
Plots of simple Newtonian energy binding conditions as a function of measured relative velocity (V_r) and projection angle from the plane of the sky (α) for Abell 3528 (*left*), 1750 (*middle*) and 3395 (*right*). The dashed lines are the limiting cases for bound systems, thus all orbit solutions to the right are unbound, while those to the left are bound. The measured relative velocity from our data is indicated by the solid vertical lines and its 68% confidence region is shown with the cross-hatching.

One of the key elements of our discussion for the three clusters we studies was whether the systems were bound and the stage of the merging process. Fig. 1 shows the orbital solutions for each of the three pairs of subclusters. As the figure shows, all have bound solutions.

3   Mass Distributions

As part of this project, over the past few years, we derived the mass distributions for several clusters and combined these to generate a cluster mass function. Most recently, we studied A3571 and then combined the mass measurements with published data to derive the cluster mass–temperature function.

We derived the mass distribution for A3571 (Nevalainen, Markevitch, Forman 2000, ApJ, 536, 73). As with our previous study, the Navarro, Frenk, & White "universal profile" is a good description of the dark matter density distribution in A3571. Also, as before, the gas density profile is shallower than the dark matter profile, scaling as $r^{-2.1}$ at large radii, leading to a monotonically increasing gas mass fraction with radius. Within r_{500} the gas mass fraction reaches 0.19 yielding an upper limit to the cosmological matter density of $\Omega_m < 0.4$.

Also, we used available mass measurements to derive a mass-temperature relation (Nevalainen, Markevitch, Forman 2000, ApJ, 532, 694). Our sample consisted of apparently relaxed clusters for which the total masses are derived, assuming hydrostatic equilibrium. The sample provides data on cluster X-ray emission-weighted cooling-flow-corrected temperatures and total masses up to r_{1000}. The resulting M-T scaling in the 1-10 keV temperature range is significantly steeper than the self-similar relation. For any given temperature, our measured mass values are significantly smaller compared to the simulation results of Evrard, Metzler, & Navarro that are frequently used for mass-temperature scaling. The higher temperature subsample ($kT_{\dot{c}}=4$ keV) is consistent with the self-similar prediction, allowing the possibility that the self-similar scaling breaks down at low temperatures, perhaps due to heating by supernovae that is more important for low-temperature groups and galaxies, as suggested by earlier works.

4 Temperature Structure of Clusters

We have completed the spectral analysis of about 55 clusters observed with ASCA using the method described in Churazov, Gilfanov, Forman, & Jones (1996 ApJ, 471, 673). For our nearly complete flux limited sample of about 55 clusters, we have generated temperature maps as described above. We are finishing the classification into several morphologically similar groups.